This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824269.

Project Acronym:	**infra4Dfuture**
Project Title:	**Infrastructure for the Future**
Project Number:	**824269**
Topic:	**MG-2-4-2018 – Coordinating national efforts in modernizing transport infrastructure and provide innovative mobility services**
Type of Action:	**Coordination and Support Action (CSA)**

D1.2 – Joint vision on transport infrastructure innovation until 2040

Version 3.0

Deliverable:	D1.2– Joint vision on transport infrastructure innovation until 2040
Work Package:	WP1: Strengthening transport infrastructure partnerships and alliances
Due Date:	M10
Submission Date:	30/09/2019
Start Date of Project:	01/10/2018
Duration of Project:	24 Months
Organisation Responsible of Deliverable:	Rijkswaterstaat (RWS)
Version:	3.0 – 30 September 2019
Status:	Final, for submission to EC portal
Author name(s):	Ruud Smit (RWS) Johan Jonsson (Trafikverket) Bernard Gyergyay (BASt)
Reviewer(s):	Ursula Blume (BASt) Richard van der Elburg (RWS)
Nature:	☒ R – Report ☐ P – Prototype ☐ D – Demonstrator ☐ O - Other
Dissemination level:	☒ PU - Public ☐ CO - Confidential, only for members of the consortium (including the Commission) ☐ RE - Restricted to a group specified by the consortium (including the Commission Services)

CONTENTS

1 Executive Summary

This document provides a consolidated description of eight innovation focus areas that are key in delivering innovation and implementation actions in the context of the three infrastructure capabilities for 2040 that have been described in deliverable D1.1 '*Stakeholder map for transport infrastructure innovation*'. Each Innovation Focus Area (IFA) description includes the strategic context and challenges, expected impacts 2030, and indicative topics for alignment and possible co-programming between national and European programmes and initiatives for innovation and implementation.

INNOVATION FOCUS AREAS FOR INFRASTRUCTURE INNOVATION AND IMPLEMENTATION

Capability 1: Infrastructure optimally meeting end user needs
The ability to provide optimal transport infrastructure network capacity in order to accommodate increasing transport needs, and balancing cost, performance, safety and risk to provide infrastructure as a high quality service to end users.

Innovation Focus Area: Network performance
Innovation Focus Area: Integrated infrastructure network management
Innovation Focus Area: Responsible and innovative procurement and finance

Capability 2: Infrastructure meeting environmental and social sustainability needs
The ability to embed transport infrastructure networks in their immediate surroundings, optimally balancing interests from economy, society, and environment.

Innovation Focus Area: Decarbonisation of infrastructure management
Innovation Focus Area: Preserving the environment
Innovation Focus Area: Integrating multi-layer networks and nodes

Capability 3: Infrastructure achieving added value from digitalisation
The ability to harvest the benefits from digitalisation in internal processes of transport infrastructure management (e.g. planning, design, construction, operation, end-of-life) as well as in the relation between transport infrastructure management and its end user (smart mobility and logistical services, individual end users).Use digitalisation to support the achievement of sustainability targets and provide a better service to infrastructure end users.

Innovation Focus Area: Smart data and information ecosystem for accommodating automated and connected transport
Innovation Focus Area: Information provision for process optimisation in infrastructure management

The document builds from input from experts participating in the first expert workshop 25-26 February 2019, the guidance from the second stakeholder conference on 22 May 2019, and comments from the consultation with the consortium members on the previous draft dating 1 August 2019.

This deliverable D1.2 is key input to work package 2 ('*Developing structures enabling effective transnational coordination of existing and future innovation programmes'*) and work package 3 ('*Collaborative professional competence building*').

Further, this deliverable will be used to communicate with relevant stakeholders for transport infrastructure innovation and implementation in order to raise their awareness, understanding and possible involvement e.g. in Innovation Focus Areas.

As such, the document is intended as a starting point or initiation context for national transport infrastructure authorities (NTIAs) that would like to coordinate and collaborate on (parts of) the described IFAs from their national and European programmes. They are encouraged to do so from the existing structures and platforms in order to reinforce opportunities for leveraging their common innovation activities across the multimodal infrastructure networks. Over the next months towards summer 2020, the infra4Dfuture initiative will stimulate and facilitate the establishment of such 'NTIA collaboration groups', and will invite them to consider their common priorities for alignment and co-programming innovation actions across the portfolio of their national and European programmes and initiatives, and do so with a focus on the years until 2030, and a further outlook towards 2040. The results from these activities will be presented in deliverable D1.3 '*Joint innovation pathways until 2040*'.

The innovation focus area descriptions presented here hold many interdependencies. It is expected that this remains the case in the further elaboration on them from the various 'NTIA collaboration groups'. This implies a inevitable need with many if not all of NTIA collaboration groups to coordinate with each other in order to effectively build synergies between their priorities for alignment and co-programming and that of the other groups. This in turn implies that in setting their on key priorities for innovation coordination and collaboration, the various NTIA collaboration groups will have freedom to amend the descriptions presented in this document.

2 Introduction

2.1 Purpose of the Document

This document provides a consolidated description of eight innovation focus areas that are key in delivering innovation and implementation actions in the context of the three infrastructure capabilities for 2040 that have been described in deliverable D1.1 '*Stakeholder map for transport infrastructure innovation*'. Each Innovation Focus Area (IFA) description includes the strategic context and challenges, expected impacts 2030, and indicative topics for alignment and possible co-programming between national and European programmes and initiatives for innovation and implementation.

This deliverable D1.2 is key input to work package 2 ('*Developing structures enabling effective transnational coordination of existing and future innovation programmes'*) and work package 3 ('*Collaborative professional competence building*'). Further, this deliverable will be used to communicate with relevant stakeholders for transport infrastructure innovation and implementation in order to raise their awareness, understanding and possible involvement e.g. in Innovation Focus Areas.

As such, the document is intended as a starting point or initiation context for national transport infrastructure authorities (NTIAs) that would like to coordinate and collaborate on (parts of) the described IFAs from their national and European programmes. They are encouraged to do so from the existing structures and platforms in order to reinforce opportunities for leveraging their common innovation activities across the multimodal infrastructure networks.

2.1.1 Task 1.2 'Defining the focus areas for infrastructure innovation'

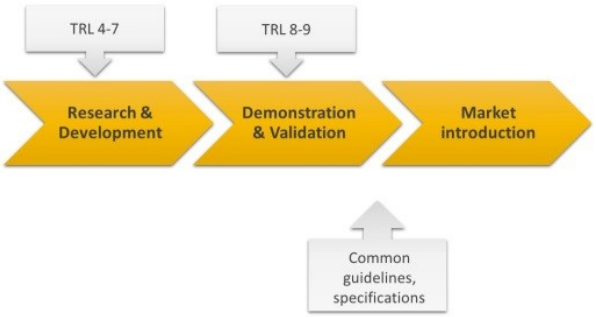
Task 1.2 is described as follows in i4Df's 'Description of Action':

> *Task 1.2 Defining the focus areas for innovation relevant to the joint infrastructure capabilities*
>
> *Task leader: RWS*
>
> *Core partners: RWS, TRC, CERTH/HIT, LVC, TRV, BASt*
>
> *Participants: all consortium partners*
>
> *The aim of this task is to define the focus areas for infrastructure innovation. A first expert workshop, in M5 (organised under WP4), will identify innovation focus areas relevant to each of the infrastructure capabilities until 2040.*
>
> *Building on the readily available documentation and capability descriptions from task 1.1, the aim is to consolidate a manageable number of emerging focus areas and to describe them in sufficient detail within the framework of the joint vision on infrastructure capabilities from task 1.1 (challenges, scope, expected impacts, time lines). Experts from WP2 and WP3 will join in on this workshop allowing maximum cross fertilisation with their activities.*
>
> *A second stakeholder conference (M8) will be organised with the decision-making levels from the representing European bodies in order to consolidate the results of the*

first expert workshop. This conference will result in a clear innovation ambition of the strategic stakeholders involved. This will be the reference for the further tasks under this WP as well as the tasks of WP2 and WP3.

2.1.2 Deviations from 'Description of Action' (DoA)

The timeline indicated in the DoA, for delivering innovation and implementation on each of the capabilities has not been provided in this document. In the stakeholder consultation the project team found that such time line is too complex to express in just one single indicator as it involves assessment on many variables such as readiness levels and typical runtime of staged development from research and development, to demonstration and validation in life practice, and to market introduction/deployment up to larger network scales (see figure). This multi-criteria assessment will have to be made in later stages when the NTIA collaboration groups will elaborate on the IFA descriptions provided in this document.



Therefore, the decision was made to forward this attribute in the description to the delivery process for D1.3 '*Joint innovation pathways until 2040*'. The expectation is that by then, the groups would be able to indicate the stage in the innovation delivery process for their key priorities in aligning and possible co-programming (see figure).

2.2 Delivery process

2.2.1 Sequence of actions

The following activities have contributed to the preparation of this deliverable:

i) **Expert workshop.** This document builds on the results from the first expert workshop 25-26 February 2019. From this workshop the descriptions of challenge, scope and expected impacts for an original number of fourteen Innovation Focus Areas (IFAs) were drafted.

ii) **Second Stakeholder Conference.** The first draft of this document –presenting fourteen IFAs- was distributed among the invitees to the second Stakeholder conference on 21 May 2019. From their guidance a second draft of this deliverable was edited. On the whole the stakeholders congregated in this conference clearly recognised the benefits of the initiative. The main issues being to reduce the number of IFAs in view of the many overlaps, and the recommendation to engage with existing structures and platforms (on basis of the consolidated eight IFAs).

iii) **Consultation of the consortium members.** From the comments of consortium members that were consulted on the second draft of this deliverable this third and final version of the document was edited. This consultation resulted in minor amendments and edits, reinforcing the general support for this document.

3 Capabilities for 2040 and corresponding innovation focus areas

Notice: The innovation focus area descriptions presented here hold many interdependencies. It is expected that this remains the case in the further elaboration on them from the various 'NTIA collaboration groups'. This implies an inevitable need with many if not all of NTIA collaboration groups to coordinate with each other in order to effectively build synergies between their priorities for alignment and co-programming and that of the other groups. This in turn implies that in setting their on key priorities for innovation coordination and collaboration, the various NTIA collaboration groups will have freedom to amend the descriptions presented in this document, such as on the indicated topics for innovation and implementation (section 3.x.x.3 of each IFA description).

3.1 Infrastructure optimally meeting end user needs

The ability to provide optimal transport infrastructure network capacity in order to accommodate increasing transport needs, and balancing cost, performance, safety and risk to provide infrastructure as a high quality service to end users.

Guiding objectives for 2040

- Full accommodation of the anticipated development in transport demand across the network, achieving effective alignment between the surface infrastructure networks through *interoperability* and *synchromodality*.
- Effective management of resources and assets, and high availability throughout the *whole infrastructure lifecycle*, from planning and design to end of life.
- Effective, adaptive integration and rapid implementation of innovations across the delivery process chain.
- Significant *reduction of **T**otal **C**ost of **O**wnership (TCO)*, *e.g.* reduction by 30% for infrastructure managers.
- *Zero fatalities* and severe injuries of infrastructure workers and end users through *Vision Zero*.
- *Resilience* to natural and man-made hazards, including adaptation to *climate change*.
- An *affordable* high capacity infrastructure that supports end users' service combinations of mobility and logistics.
- Comprehensive and consistent *framework of performance indicators* for the management of the integrated, multi-modal network, available by 2030.

3.1.1 Innovation Focus Area: Network performance

3.1.1.1 Strategic context and challenges

Transport infrastructure owners and their end users are currently facing a rapid change in the mobility and the transport infrastructure sector. Digitalisation is one of the main causes for these rapid changes as it enables infrastructure owners and their end users to benefit from e.g. new information sources. They enable more informed decisions about the services that

owners provide in support of the decision making by the end users on their planned journey e.g. state of infrastructure, route, modes, time and cost.

In addition, end users are also becoming more conscious about the use of the transport infrastructure and they put more value on aspects such as sustainability and access to digital services whilst using the infrastructure. Hence, it is clear that infrastructure owners need to broaden their understanding of end user needs (i.e. mobility and logistics) and the possibilities to influence in order to provide satisfactory services and access to infrastructure. From an end user perspective the division line between modes becomes more blurred as new information sources influence daily mobility decisions.

Current key performance indicators (KPIs) and assessment techniques used by infrastructure owners do not accurately reflect the changes. This puts infrastructure owners into the position to develop new dynamic KPIs taking into consideration the needs and requirements of the end users.

Regardless of digital layers, transport infrastructure has to offer the necessary availability and service for the end user in a reliable and safe way.

To cope with increasing traffic volumes calls for a better ability to plan and organise construction and maintenance work with minimum interruptions regarding duration and impact, especially for critical nodes i.e. bridges, tunnels, intersections and locks.

For management of accidents and incidents as well as for interruptions due to man-made or natural events, emergency plans are necessary to keep interference with traffic flow to a minimum. Services required by private users and industrial use may be different and can be used to define priorities.

- Innovations in this area are expected to facilitate infrastructure owners to respond to the emerging end users' mobility and logistics needs and infrastructure availability. Among others, this will result in the development of new multimodal KPIs, data collection approaches, analysis techniques and assessment tools.

3.1.1.2 Expected impacts 2030

- Significant increase in uniformity of infrastructure management and decision making across the national networks across Europe from a comprehensive and consistent common framework of KPIs. This will result in higher effectiveness and efficiency from investments in maintenance, replacement and renewal.

- Improved reflection of end users' needs and requirements for the provision of infrastructure services, including availability and the inclusion in the national transport policy framework. In combination with real time service approaches from risk-based scenarios and strategies this will deliver rapid response from the operations, significantly limiting and reducing incursion on the transport flows.

- Significantly improved ability to reroute strategic transport flows over the integrated networks in case of natural or man-made events, such as drought or failing assets.

3.1.1.3 Innovation and implementation

- Intelligent prediction of maintenance: Models for a systematic cross modal and cross border infra structure management are required to achieve a proactive network maintenance planning, avoiding unplanned maintenance measures and developing sound alternatives for the overall traffic volume. A digital twin, including moving objects, forms the base to support forecast and planning of the infrastructure use and state. Such a tool allows a condition based approach to schedule construction as well as maintenance measures. Building on a smart infrastructure assessment programme, the digital twin should enable assessment of critical infrastructure assets e.g. bridges, tunnels, intersections, locks on their vulnerability, and of potential approaches and measures for eventual rerouting traffic in case of natural and man-made incidents.

- Accident/incident management: Predicting the probability of accidents/incidents to forecast and/or assess the impact of such events is an important ability for infrastructure authorities. New technologies that allow emergency plans for timely interventions have to be developed from both a cross-border and cross modal perspective. This applies for both man-made and natural events.

- Ergonomically optimised infrastructure design: The concepts of "forgiving infrastructure" and "self-exploring infrastructure" are principles to be further developed to minimise impact and duration of disturbances on the infrastructure network. Artificial intelligence (AI) and related materials, methods and processes will support achieving the intended goals.

- New materials, systems, and techniques: Smart design and construction materials as well as non-destructive testing methods through sensor technology will help to improve intelligent prediction the infrastructure state. Among others, this can include automation in maintenance and construction processes, and remote manufacturing.

- Big data: Real time remote condition monitoring and robotics automatically generate data. More value from this data is a prerequisite for the development of a digital twin including moving objects. Data sharing is also required to reach goals as intelligent prediction of maintenance as well as suggesting e.g. real time user specific road routing through inter-alia swarm intelligence. A key issue to be solved is data openness.

- Adopting cross-sectoral innovations: The approaches of the Shift2Rail initiative, e.g. service operation timed to the second, and the systemic approach of the railway network used for its operation, construction and maintenance should be investigated on their potential transfer and application in the management of the road network. The rail mode is based on the principle that the railway is a system.

- Understanding the end user: Infrastructure authorities need to develop updated definitions of their end users (groups) and assess their changing needs and requirements until 2040. These definitions need to recognise and appreciate the varying acceptance and user needs for solutions across the EU. A dynamic exchange with end users is required to reflect the fast changing needs in the coming years.

- Consistent framework of performance indicators: The current sets of KPIs used in infrastructure management need to be thoroughly reviewed and updated. This includes

the actual definition of the KPIs, their measurement techniques and the threshold values. The KPIs should reflect a wide set of end user needs, also including needs from the logistics sector. Market observations and big data, i.e. more value from data, could also be used to anticipate user needs. Gender issues as well as users with reduced mobility should be included.

- Interoperability: Integrated logistics planning and electronic transactions (e.g. block chain) along the logistics delivery chain need to be developed.

3.1.2 Innovation Focus Area: Integrated infrastructure network management

3.1.2.1 Strategic context and challenges

Infrastructure management needs to take the next step towards achieving a truly integrated, multimodal network across Europe delivering high quality services to its end user. A key factor in this step is the introduction of life-cycle management (LCM) as an integrating framework for the management processes of the individual bodies. The benefits of an integrated infrastructure LCM from planning, building, operating to decommissioning are widely accepted, but the deployment of this approach needs to be facilitated further. There is a need to balance the use of affordable technical assets and good value services for maintenance and operation to ensure a high service quality to end users at a justifiable cost.

In general, transport infrastructure must become more reliable with higher service quality at lower costs. This can be achieved by using new technologies and methods to improve traffic flow, safety level and maintenance operations with the right action at the right time. More value from data can help with the underlying information base. Improved interconnection between hard and soft transport sub-systems through integrated mobility management and information to end users approaches has a high potential in contributing to the guaranteed availability of transport infrastructure.

During the operational phase, infra managers need to consider approaches to ensure their networks' safety, security and resilience against serious natural or man-made incursions.

It is therefore necessary to engage in a holistic examination and appraisal of the transport infrastructure to establish key risks for the networks operations, such as, the degree to which procedures are in place for preparing, planning, coping with and adapting to unexpected and adverse events. Following the results of this risk analysis, proactive measures to prevent these threats may be planned and taken, but also, procedures to face occurrence of hazards must be elaborated and activated.

Use of new technologies and innovative technological tools will ensure integrity of the transport infrastructure and safety of end users in a most effective way.

3.1.2.2 Expected impacts 2030

- Significant improvement and uniformity in decision making in the management of national networks across Europe. This will be enabled through the delivery of a comprehensive and consistent common framework approach that is life-cycle and risk based, and that is supported by a comprehensive and consistent toolbox of methods,

models and systems. This enables cross-border assessment of both ongoing concern investments in maintenance, replacement and renewal and eventual natural and man-made incursions.

- Significant improvement of reliability, availability, maintainability, safety, sustainability and economy of the infrastructure networks across Europe through the increase in integration within and across the modes. This enables scales of economy through cross border optimisation of performance, cost and residual risk.

- Significant network scale support to digital end user oriented applications for transport services through the delivery of a seamless digital services platform that is rooted in the primary processes in the infrastructure delivery chain and that ensures seamless comprehensive and consistent data/information approaches, systems and structures across the national and cross border networks.

3.1.2.3 Innovation and implementation

- Quality orientated process control: New approaches for quality oriented process control are needed that consider the whole infrastructure life cycle and that build on coherent and consistent sensor measurements and subsequent data processing.

- Cost efficient, safety-orientated and intelligent maintenance planning systems: The next generation of maintenance planning should include better methods, and models that add intelligence and enable predictive maintenance, replacement and renewal decision making. Examples are a real time digital twin with ability to determine optimal availability levels considering dynamic traffic flow patterns.

- Integrated mobility management systems: Next generation of mobility management systems is needed to optimise infrastructure larger construction projects (replacement, renewal) on minimal impact on traffic flows and accessibility.

- Integrated journey planning applications: Implementation of services supporting synchro modal journey planning, rely on tools for users. Such tools should include attributes such as travel costs and reliable traffic info and logistics related topics. This requires a clearer understanding of the data formats required and identification of the potential of new data sources.

- Conceiving sustainability targets: Social, economic, technical and environmental optimisation studies and demonstrations/showcases to meet sustainability targets of life cycle management.

- Life-cycle costing (LCC) principles: The use of Life-cycle costing (LCC) to justify investments and maintenance costs to achieve effective operations.

- Future proofing of infrastructure planning: An infrastructure adapted to future needs and technologies, i.e. infrastructure has to be planned in a multi-functional manner considering systems to be installed together within the infrastructure. Focus should be on circular economy, i.e. recycling of materials and structures and an energy-neutral infrastructure.

- Digital twinning of the integrated transport infrastructure network: The concept of digital twins in infrastructure asset management is emergent as it holds significant potential for optimal decision making, reducing invasion in ongoing concern and failure cost from maintenance, replacement and renewal. This development needs to be taken to the next level i.e. towards the integrated network scale. Key attributes in the development are their applications for risk-based asset management approaches that follow the principles of Life Cycle Management (LCM), Life Cycle Analysis (LCA), Condition Based Management (CBM), and Performance Based Standards (PBS), Efforts should deliver a common European framework for deployment in the specific national setting.

- Next generation safety measures: Development of intelligent measures for the improvement of the safety for infrastructure workers and end users.

3.1.3 Innovation Focus Area: Responsible and innovative procurement and finance

3.1.3.1 Strategic context and challenges

Transport infrastructure owners and managers are facing a number of challenges in the implementation of innovations in the process of modernising the European transport infrastructure. Procurement is at the heart of this process as it manages the interaction and the risk sharing model between the public sector (i.e. usually the owner of the infrastructure) and the private sector (i.e. the contractors) when innovations are being deployed during the modernisation of the transport infrastructure. Additional pressure is put onto infrastructure owners and managers to use their purchasing power to support wider societal (e.g. support of SMEs, social return clauses to support apprenticeships) and environmental (e.g. use of recycled material) goals. Current procurement procedures are often seen as a barrier for the application of innovative approaches, transnational cooperation and the achievement of targets for wider societal goals such as sustainability. Procurement procedures and instruments need to evolve with the innovations that will be delivered on the transport infrastructure network to speed up the uptake and implementation of innovations.

3.1.3.2 Expected impacts 2030

Innovations in this area will strengthen the role of procurement in the early phases of the transport infrastructure projects when decisions are made about the scope, the goals on innovation in the project, and collaboration with (transnational) public partners and the private sector. This will be achieved through novel collaboration structures and procurement parameters, developed and tested in a multi-modal and transnational context. The expected impact is a quicker and easier implementation of innovations during the modernisation of the European transport infrastructure.

3.1.3.3 Innovation and implementation

- Life-cycle costs analysis in innovative contracting: Innovative contracting for construction and maintenance could play a key role in providing greener and more cost efficient transport infrastructure. The role of life-cycle costs analysis (LCCA) could be strengthened as a selection criterion during tendering procedures, considering aspects such as carbon footprint, material durability and other environmental impacts. Further, innovative contracting could support shared and unified procurement platforms in

Europe for generic systems, components and subsystems (e.g. as already used in the automotive and aviation industries) in order to move away from customised locked-in systems.

- Risk sharing approaches: Building on recent (national) work, common innovative risk sharing and management approaches could be established to provide suitable models to share risk between infrastructure owners, end users, designers (e.g. design-build tenders) and contractors.
- Simulation models in procurement: In order to encourage innovative practices in contracts, innovations need to be assessed to optimise procurement processes e.g. by the application of simulation models. The use of proof of concept demonstrators for innovations will also facilitate and speed up procurement and deployment procedures.
- Innovative financing schemes: Linked to procurement processes are also innovative financing approaches to raise funds for new infrastructure investments through direct payment of the infrastructure by e.g. the user including the relations between users, mobility providers, and contractors.

3.2 Infrastructure meeting environmental and social sustainability needs

The ability to embed transport infrastructure networks in their immediate surroundings, optimally balancing interests from economy, society, and environment.

Guiding objectives for 2040

Compliance with COP21 and Agenda 2030/UN targets for sustainable development in the context of European objectives and targets.

- Minimise carbon footprint of the whole service-life of infrastructure, including the infrastructure delivery process chain. This includes achieving energy neutrality of the infrastructure management operations (e.g. lighting, signalling, data collection, information provision, lifting and ventilation) up to larger network scales.
- Facilitate the transition in the energy pool of the transport modes and supporting measures to improve energy-efficiency of mobility services (passengers, freight).
- Collaborate on the minimisation of the impact on the environment, in particular concerning the impact of noise, vibration and pollutant emissions. This concerns the share of the impact that is contributable to infrastructure management.
- Collaborate on the optimal net benefit from embedding infrastructure in the spatial setting. This concerns the 'how' in infrastructure governance, balancing benefits for the economy, society and environment in the planning and approval stage.

3.2.1 Innovation Focus Area: Decarbonisation of infrastructure management

3.2.1.1 Strategic context and challenges

In itself, the share of infrastructure management in the total carbon emissions from the transport system is very limited. Nevertheless, the transport infrastructure authorities will need to deliver their share in the transition towards a circular and decarbonised society. In addition,

infrastructure management holds significant leverage on the energy transition and efficiencies in the other components of the transport system; on transport means (e.g. through facilitating and stimulating the uptake of electrification, renewable energy); on transport operations for passengers and freight (e.g. through intelligent traffic management strategies and operations), and on the relevant manufacturing construction industry (e.g. through green procurement). Furthermore, the surface area and adjacent areas of transport infrastructure offer opportunities for (synergies in) harvesting energy.

Infrastructure authorities across Europe and beyond have already invested significantly in these developments. However, this mostly concerned limited projects and programmes in limited settings, often aiming at proof of concept or demonstration. In individual cases countries have established larger scale action programmes for their networks.

3.2.1.2 Expected impacts 2030

- Better economies of scale from common objectives and perspectives providing larger opportunities for industry as well as infrastructure managers. The innovation focus is on delivering a validated, next level suite of models, methods and data.
- Closer integration of the strategic transport networks on national and European scale.
- The increased production of renewable energy on transport infrastructure's assets.
- The seamless legislative integration of the new processes.
- The reduction of carbon emissions of infrastructure management processes towards neutrality through showcasing more efficient technological operations, e.g. operating tunnels with LEDs.

3.2.1.3 Innovation and implementation

- Framework and strategies for the distribution of costs, benefits and risks across the actors in the manufacturing and delivery chain:
    - Approaches to consider deconstruction/recycling during the planning and design phase of the lifecycle.
    - Approaches to enhance the reuse or recycling of construction materials at minimal (energy) costs while complying with technical requirements.
- Next generation common toolbox for applying circular economy principles at low carbon energy costs:
    - Methods for manufacturing, refurbishing or rehabilitating transport (related) infrastructures with the objective to significantly extend functional life spans of infrastructures and its key elements.
    - Performance-based design models and manufacturing techniques (e.g. 3D-printing) with the objective to substantially reduce materials consumption.
    - Common ecological assessment methods and models for alternative materials.

- Assessing the sustainability of scaled-up approaches integrating circular economy principles: Applying circular economy principles does not necessarily translate into more sustainable practices. Robust life-cycle assessments are needed to support the deployment of innovative solutions. Hence the following shall be pursued:
    - Development of common databases related to (but not limited to) hazardous substance contamination/release, carbon footprint, energy and virgin material consumption over infrastructure service-life.
    - Harmonisation of calculation protocols and tools for life-cycle analysis ensuring transparency, comparability and reliability of assessment results.
- Developing methods, models and guidelines for sustainable procurement practices:

  Public authorities' involvement is key to a successful transition of new approaches into practice. Procurement practices should evolve to foster a strong, sustained demand for low carbon, resource efficient solutions and help innovative companies to reach proper economies of scale for a wide diffusion of best technologies and best practices.
    - Development common data, methods and models enabling sustainability assessment across the infrastructure life cycle.
    - Transfer of good procurement practices among infrastructure authorities.
    - Development and transfer of common frameworks, guidelines, and tools for sustainable public procurement, building upon the latest scientific/technical/organisational advances.
    - Preparation of transport authorities for the energy transition:
    - Integration of refuelling and recharging infrastructures for electric vehicles, including energy logistics at rest and parking areas.
    - Adaptive lightning systems to reduce energy consumption based on traffic volumes, luminance external values and road characteristics. Use of alternative ways to reinforce luminance at the entrance of tunnels by deploying natural light through mirrors and wave guides.
    - Identification and assessment of the potential of harvesting renewable energy on infrastructure and its verges and assessment of the related challenges, e.g. impacts on land use.
    - Strategies for eco-efficient traffic flow management across corridors and routes.
    - Energy management of the transport process, including cross-modal alignment and investments of the transport network in respect to the energy network.
- Foster best practices as new standards and share a cross-modal strategic programming approach:
    - Development of supporting policies, including the fostering of new or harmonisation of existing standards.

- Support of the social acceptance of the transition process.
- Examples of partnerships of road authorities and TSO/DSO to foster shared standards.
- Facilitating modal shift towards „low energy“ transportation

3.2.2 Innovation Focus Area: Preserving the environment

3.2.2.1 Strategic context and challenges

In itself, the impact of infrastructure management on the environment is very limited in comparison to that of the transport process itself. Nevertheless, the transport infrastructure authorities will need to deliver their share in reducing that impact. In addition, infrastructure management holds significant leverage on the level of impact from the other components of the transport system, including the manufacturing construction industry (e.g. through green procurement). Furthermore, their responsibility for the surface area and adjacent areas of transport infrastructure offer opportunities for mitigation and adaptation.

Infrastructure authorities across Europe and beyond have already invested significantly in these developments.

3.2.2.2 Expected impacts 2030

- Improvement of quality of life, in particular in the immediate surroundings of the infrastructure networks.
- Improvement of environmental performance of the transport system as well as improvement of habitat quality and biodiversity.

3.2.2.3 Innovation and implementation

- Reduction of noise and vibration:
  - Next generation of source measures (reducing the emission from wheel-surface contact)
  - Next generation noise abatement techniques, systems and materials.
  - Advanced traffic control and management strategies
  - Dose-response relationships (to improve the understanding of the impact of noise on quality of life).
  - Next generation tools for impact assessment, assessment/simulation of design, implementation, operation and maintenance, and simulating noise perception (e.g. immersive virtual reality).
- Reduce costs of noise mapping activities:
  - Automation of the process of noise mapping, considering the possibility of using mobile phones, could help to improve the accuracy level of noise maps.

- EU-regional scale monitoring network, interconnecting public databases and further information systems (noise, air quality, traffic and meteorological data), enabling a comprehensive overarching insight of the environmental impact of combined national infrastructure networks, including relevant regional sections.

- Reduction of NO_x, PM10, PM2.5 emissions to air, soil and water: Assessment on possible common pricing techniques unified on European level based on pollutant emissions (noise, air, water) will lead to a re-thinking and the investigation of possibilities to mitigate air pollution directly at the source (smaller cars, gas treatment, brakes made of different materials).

- Treatment of emissions: Explore and implement the possibility to keep treatment options as natural as possible, taking into account the related space consumption and considering biodiversity. The implementation of on-site water run-off treatment using the local soil in the existing network should be facilitated for both the road and rail mode.

- Preservation of habitats and biodiversity: Based on a common understanding of what the habitats are and how they are affected by infrastructure (and transport), it is necessary to connect the whole habitats, to allow the migration of species. Integrated solutions need to be taken into account reflecting the various aspects related to environmental impacts. Opportunities of the existing space belonging to the infrastructure have to be investigated to preserve and improve biodiversity.

- Introduction of new transport concepts: Environmental impact assessment (emissions, noise, safety, security, spatial).

3.2.3 Innovation Focus Area: Integrating multi-layer networks and nodes.

The Trans-European Transport Network (TEN-T) is the main action plan for comprehensive transport infrastructure development throughout the European Union and is -in combination with national transport and infrastructure policies- essential for the ambition to realise a single transport area in Europe. While responding to economic and private users' needs, this infrastructure development must fulfil key societal requirements, such as balanced accessibility and sustainability.

Nodes are key elements of the TEN-T network and have to respond to growing mobility needs and increasing freight transport by implementing new logistic concepts, ensuring transport modes' seamless interconnection and accommodate spatial-economic growth and urban expansion (housing, working, facilities).

An effective integration of a node in the TEN-T core network corridors is complex. Different spatial scales, modalities, sectors and stakeholders are concerned and all have to be taken into account when optimizing the integration of solutions for accessibility and profitability of mobility on the one hand with vitality and liveability of nodes becoming increasingly important on the other. As mobility and infrastructure demands grow and innovate fast, and increasingly impact socio-economic development as well as accessibility and spatial and environmental quality of nodes, there is need multilayer approach that includes spatial, network, temporal, value, institutional and implementation issues that need to be resolved simultaneous on three levels: local (i.e intra-urban locations), urban-regions (i.e. the level of the Daily Urban System

and Functional Urban Area) and trans-national (TEN-T Network). This allows for a more integrated perspective at investments in mobility, infrastructure, passenger transport and freight logistics from (inter)national (corridor), regional and local perspectives.

Making use of the results of different European research project (e.g. H2020 project Vital Nodes and CEDR Call Freight and Logistics in a Multimodal Context) there is an opportunity to develop an integrated approach for infrastructure and land-use planning that connects the worlds of infrastructure management, mobility and logistical services and spatial development policies.

3.2.3.1 Expected impacts 2030

The integrated approach enables authorities to achieve an adaptable, sustainable and robust transport network, offering users an optimally integrated mobility chain and close coordination of infrastructure and spatial development. The expected impact of the wide-scale deployment by public authorities of the toolbox and recommendations from VitalNodes is a more effective planning in terms of investment costs and a planning process that takes less overall time and costs (following a guiding objective of 30% reduction in planning time and cost of mitigation measures) that also leads to higher social-economic revenues, as well as reliability of the transport system and liveability in the urban areas involved.

3.2.3.2 Innovation and implementation

- Integrated investment perspectives. cooperation between government levels (local, regional, national, EU), government agencies, expert networks and (market) stakeholders will produce innovative mobility solutions. This allows for a more integrated perspective at investments in mobility, infrastructure, passenger transport and freight logistics from (inter)national (corridor), regional and local perspectives;

- Integrated policy perspectives. More sustainable and efficient (TEN-T and comprehensive) networks and an optimal integration between infrastructure planning and spatial planning. Increasingly involvement and coordination between freight and logistic operators, port authorities, infrastructure providers, spatial planners and financiers the planning processes for transport infrastructure on the three different levels (local, national, European).

3.3 Infrastructure achieving added value from digitalisation

The ability to harvest the benefits from digitalisation in internal processes of transport infrastructure management (e.g. planning, design, construction, operation, end-of-life) as well as in the relation between transport infrastructure management and its end user (smart mobility and logistical services, individual end users).Use digitalisation to support the achievement of sustainability targets and provide a better service to infrastructure end users.

Guiding objectives for 2040

- Facilitate the transition towards smart mobility concepts (freight and passenger) for emerging concepts for automated mobility, e.g. Connected Cooperative and Automated Mobility (CCAM) for road and Automatic Train Operation (ATO) for rail.
- Proactive position of the infrastructure manager within the infrastructure related data-driven ecosystem, including clearly defined data flows between multimodal, national and sectoral stakeholders and a clear business model and case for investment in and maintenance of digital and virtual infrastructure.
- Ability to process internal and external raw data into smart data that can optimize infrastructure management processes, including maintenance and construction of infrastructure. Provide seamless data and information use and provision across the transport infrastructure network and logistics chain to the end user.
- Facilitation of the alignment of TEN-T core network with data and energy networks to benefit from multi-purpose digitalised networks that can cater for future digital needs, e.g. Internet of Things (IoT) and smart grid based electric mobility.
- Increase the use of automated, semi-automated and remote-piloted solutions for infrastructure maintenance and construction to improve safety for workers and reduce costs.

3.3.1 Innovation Focus Area: Smart data and information ecosystem for accommodating automated and connected transport

3.3.1.1 Strategic context and challenges

The entire mobility system is currently in a transition phase towards higher levels of digitalisation: This will result in more connected and automated functionalities, both for vehicles using the infrastructure and the infrastructure itself. The division line between “intelligence/knowledge” in the vehicle or infrastructure will become blurrier, which will have a multitude of effects on the relationship between vehicle owner, vehicle manufacturer and infrastructure manager. The coming decades will be a period for infrastructure owners and managers with guaranteed uncertainty regarding, among others, vehicle penetrations rates, automated functionalities and digital and physical infrastructure requirements. The key challenge for infrastructure owners will be to navigate these uncertain times by developing suitable governance models that foster an institutional readiness to tackle a variety of interdependent issues that infrastructure owners and managers are currently facing.Data is becoming a more and more important resource for infrastructure owners and managers, but

current data-related research activities have mainly focused on data provision and exchange to the benefits of service providers and end users, e.g. for trip planning and information provision. The role of infrastructure managers and owners in a multimodal and transnational data sharing eco-system needs to be defined and developed to enable infrastructure owners and managers to benefit more from digitalisation and big data in their internal processes, whilst securing a high level data security and privacy.

3.3.1.2 Expected impacts 2030

Innovations in this area will facilitate infrastructure managers to become institutionally ready to better plan and deploy strategies towards the accommodation of connected and automated transport on their infrastructure. This will result in new governance structures that are based on new stakeholder processes across the value chain of connected and automated vehicles. The structures and processes are established through a thorough understanding of potential impacts on the core business of the infrastructure managers that arise through varying penetration rates of mixed CAV fleets. This should place the infrastructure manager in an assertive position with a suitable business case. Aim is to deploy and manage infrastructure elements of a complex Operational Design Domain (ODD) that enables CAVs to fulfil the expected positive effects on safety, traffic efficiency and other core business activities of infrastructures owners.

Innovations in this area should facilitate infrastructure owners to use data as a valuable resource, which can optimise processes across the entire organisation and lead to cost savings, better decision making and new cooperation approaches with professional stakeholders (e.g. engineers, start-ups and researchers). Further, this can create a multimodal and transnational digital layer that interlinks various transport activities to support EU-wide services for infrastructure owners.

3.3.1.3 Innovation and implementation

- <u>The new and evolving role of the infrastructure owner in the context of the deployment of connected and automated vehicles:</u> The development of an impact assessment on the core business activities of infrastructure owners. The impact assessment needs to consider the evolving penetration rates of passenger and freight CAVs fleets. The results needs to provide clarity on the limitation of the current infrastructure (incl. tunnels and bridges) to derive approaches (e.g. limiting platooning on structurally weak infrastructure) to tackle potential side effects of the CAV deployment. Identification of CAV functionalities that can support the core business activities of infrastructure owners, e.g. the use of CAV sensor data to collection data about infrastructure condition. The newly developed “Infrastructure Support Levels for Automated driving” (ISAD) classification needs to be developed further to include wider aspects that consider the needs of infrastructure owners. This can also include aspects such as digital twins (e.g. OpenDrive) that can be used for the navigation of CAVs.

- <u>Secure, resilient and smart data and information ecosystem across multimodal and transnational networks for all users:</u> Creating a strategic vision for the role of the infrastructure owner and manager in the evolving eco-system that clearly highlights the benefits of data sharing for internal and external. This includes the development of new governance models that enable cooperations across institutional, modal and national boundaries. Investigate the role of the NAPs in enabling infrastructure managers to

benefit from better data collection and management, including the development of approached for meta-data catalogues, data quality standards, data security, data source certification and licensing. The integration of legacy systems for data management into the evolving multimodal and transnational data ecosystem.

3.3.2 Innovation Focus Area: Information provision for process optimisation in infrastructure management

3.3.2.1 Strategic context and challenges

- For many years there has been an ongoing evolution in infrastructure management towards automated design, construction control and inspections etc., involving sensors and continuous and non-destructive measurements. Infrastructure owners and managers have to adjust their working approaches to benefit from the possibilities offered by this data-driven eco-system. Ideally, all data involved in all life phases of the infrastructure should be accommodated and processed by an integrated digital twin, of which the BIM-system is the fundamental backbone.

- New (big) data from external data providers will offer new potential to benefit from digitalisation, which, if used rightly, can contribute to significant cost savings and optimisation in work processes. Artificial Intelligence (AI) can assist in this development by processing and interpreting all the already existing data that is currently not being used to any satisfactory extent, and AI may also eventually provide an important decision-support tool for infrastructure asset management. Virtual training, digital verification and validation can add tremendously to the availability and safety of the network, especially for critical nodes such as tunnels and bridges.

- The use of robotised equipment, drones or other (semi)-automated remote-piloted solutions and artificial intelligence (AI) is developing fast and applications are likely to become mainstream within the next years. Workers will work side-by-side with different forms of robotised equipment and get decision-making support from artificial intelligence. A transition phase, where old and new techniques are co-existent, is unavoidable.

3.3.2.2 Expected impacts 2030

Innovations in this area should facilitate infrastructure managers to use data as a valuable resource, ultimately resulting in cost efficient and intelligent maintenance planning. Data acquisition through sensors in or attached to the infrastructure, remote sensing by drones or high speed inspection vehicles and in-car data will gradually replace visual inspection and static extraction of specimens to control the specification and mechanical and chemical behaviour. This transition requires a relative long transition period in which data acquainted by new techniques must be validated and calibrated with respect to current techniques. The governance structures of infrastructure managers will be adjusted to include AI into decision-making processes across the entire organisation.

Innovations in this area will facilitate infrastructure managers, among others, to improve workers health, reduce costs, and avoid traffic hindrance. It is expected that there will be a significant reduction of the labour shortage in the road construction and maintenance sector by developing less labour intensive processes for construction and maintenance. The quality

of inspections can be improved, because up until now non-accessible locations (small pipes, under water, underground etc.) and (almost) continuous and instant monitoring opens the doors to very accurate big data analysis.

3.3.2.3 Innovation and implementation

- Data-driven and digitalised asset management:
    - Incorporation of data from sensors mounted in vehicles, trains and vessels along with data from external sources (e.g. from mobile phones) into Asset Management Systems.
    - Development of measuring systems and systems for data processing to facilitate the creation of digital twins for the existing infrastructure.
    - Identify the knowledge gaps for the interpretation of the collected data and develop models to make digitalized asset management possible.
    - Cross-modal data management and combined digital twins for road, rail and waterways/ports.
    - The use of AI to process and interpret infrastructure data, especially for data that has previously been labour intensive and time consuming (e.g. GPR-data, crack and damage detection from photos).
    - Automated Asset Management System incorporating data automatically loaded from sensors, automated decision tool and maintenance action ordering.
- Advanced approaches and strategies for automated construction, maintenance, strengthening and inspection of infrastructure by artificial intelligence:
    - Infrastructure managers need to review legal requirements and organisational structures to enable the certification of data that is processed by AIs. Certification and quality standards can support an AI-based data ecosystem with a common “language”, which can extend across the value chain of construction, maintenance and inspection processes.
    - New validation and calibration techniques for inspection data can support the acquisition of data from new and not widely used data sources. Data catalogues, data ownership and data exchange procedures will enable infrastructure managers to exchange data with contractors along the value chain.
    - An assessment of the barriers for the use of robotisation in the construction processes could facilitate infrastructure managers to foster an innovation friendly environment that enables contracts to invest in more robotized equipment. Enabling activities such as the use of digital twins, modular construction, mobile factories, 3-D printing, gaming, and Augmented Reality and Virtual Reality can support wider robotisation of construction processes.

4 Next steps towards delivery of the coordination mechanism

Over the next months towards summer 2020, the infra4Dfuture initiative will stimulate and facilitate the establishment of such 'NTIA collaboration groups', and will invite them to consider their common priorities for alignment and co-programming innovation actions across the portfolio of their national and European programmes and initiatives, and do so with a focus on the years until 2030, and a further outlook towards 2040. The results from these activities will be presented in deliverable D1.3 '*Joint innovation pathways until 2040*'.

As such, this deliverable D1.2 is key input to work package 2 ('*Developing structures enabling effective transnational coordination of existing and future innovation programmes'*) and work package 3 ('*Collaborative professional competence building*').

Further, this deliverable will be used to communicate with relevant stakeholders for transport infrastructure innovation and implementation in order to raise their awareness, understanding and possible involvement e.g. in Innovation Focus Areas.

This document is intended as a starting point or initiation context for national transport infrastructure authorities (NTIAs) that would like to coordinate and collaborate on (parts of) the described IFAs from their national and European programmes. They are encouraged to do so from the existing structures and platforms in order to reinforce opportunities for leveraging their common innovation activities across the multimodal infrastructure networks.

The innovation focus area descriptions presented here hold many interdependencies. It is expected that this remains the case in the further elaboration on them from the various 'NTIA collaboration groups'. This implies an inevitable need with many if not all of NTIA collaboration groups to coordinate with each other in order to effectively build synergies between their priorities for alignment and co-programming and that of the other groups. This in turn implies that in setting their on key priorities for innovation coordination and collaboration, the various NTIA collaboration groups will have freedom to amend the descriptions presented in this document.